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Publicising chemistry in a multicultural society through chemistry outreach

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Given the emphasis in Higher Education on community engagement in South Africa and the importance of international collaboration, we discuss a joint approach to chemistry outreach in two countries on two continents with widely differing target school audiences. We describe the history of the partnership between the chemistry departments at Rhodes University and the University of Bristol and provide an outline of the chemistry content of their outreach initiatives, the modes of delivery, the advantages to both departments and their students for involvement in various levels of outreach, the challenges they still face and additional opportunities that such work facilitated. The lecture demonstration 'A Pollutant's Tale' was presented to thousands of learners all over the world, including learners at resource-deprived schools in South Africa. Challenges to extend outreach activities in South Africa include long travelling distances, as well as a lack of facilities (such as school halls and electricity) at schools. Outreach activities not only impacted on the target audience of young learners, they also impacted upon the postgraduate and other chemistry students taking part in these initiatives. This collaboration strengthened both institutions and their outreach work and may also lead to chemistry research collaborations between the academics involved.

Introduction

In 2008, the Director and the School Teacher Fellow^{1,2,3} from Bristol ChemLabS Outreach were invited to attend SciFest Africa held in Grahamstown, South Africa. The ChemLabS team gave a series of demonstration lectures on air pollution and climate, entitled 'A Pollutant's Tale'.^{4,5,6,7} The Department of Chemistry at Rhodes University was very involved in supporting these lectures through the preparation of some of the demonstrations, which further contributed to building a partnership between these two groups. Following this meeting in April 2008, a strong relationship of cooperation in outreach activities has developed between these two universities. Bristol ChemLabS is the project name of the UK's Centre for Excellence in Teaching and Learning in Practical Chemistry which is part of the School of Chemistry at the University of Bristol.¹ The Bristol ChemLabS chemistry outreach programme engages with about 30 000 people annually, mainly school learners, in hands-on and face-to-face outreach activities and has trained over 500 PhD chemists to work with school learners over the last 6 years.

The Department of Chemistry at Rhodes University has a history of chemistry outreach. From 1998 to 2000, sponsorship was secured to provide schools with microchemistry kits provided by Somerset Educational to facilitate practical work. In 2000, the Khanya Maths and Science Club was formed to make maths and science more accessible to learners and to assist their learning in these subjects. The ongoing Khanya Maths and Science Club for grade 7–12 learners is held on Saturday mornings during school terms at Grahamstown's Albany Museum. Of the attendees 95% are from resource-deprived schools. In the context of this article the term 'resource-deprived school' will be used to describe schools in which the facilities for practical science teaching are absent or, at best, marginal. At the beginning of every year the number of learners accepted into the Khanya Maths and Science Club is capped at 120, but the numbers usually drop to between 50 and 60 during the year. The aim of the club is to engender a love of maths and science in learners. Accessible maths and science is shared in an enjoyable format with younger learners, and curriculum-based supplementary maths and science is taught to older learners. Science and maths teaching is particularly poor at resource-deprived schools.^{8,9} At least once a year club members are taken on educational outings which have included trips to the sea, private game reserves, an oceanarium and a snake park. At the annual prize-giving learners receive science books for good attendance. All the teaching is provided on a voluntary basis by postgraduate and undergraduate students, most of whom are studying Chemistry. Organisation and coordination is done by Sewry and staff of the Rhodes University Department of Chemistry. A member of the first cohort of the Khanya Club is now studying towards his PhD in Financial Statistics, and there are a number of others who are currently registered for Commerce and Science degrees at Rhodes



University. The minimal funding required to run the club is provided by Professor Tebello Nyokong, a Research Fellow in the Department of Chemistry, and by the Grahamstown Round Table.

In September 2008, an academic and four chemistry students from Rhodes University visited Bristol ChemLabS, specifically to gather information about its extensive chemistry outreach activities which could be reproduced in South Africa. The fact-finding trip, sponsored by Afrox and Bristol ChemLabS, helped the Department of Chemistry at Rhodes University to further develop their own chemistry outreach programmes for deployment in resource-deprived schools across South Africa's Eastern Cape Province. During the visit the group observed a number of outreach activities, including a Primary Science Day at a Bristol school, spectroscopy tours for pre-university students and a summer school for Spanish students held at the University of Bristol. Subsequent to the Bristol ChemLabS visit by the Rhodes University delegation there was a 3-week visit to Grahamstown by two University of Bristol chemistry postgraduates, highly experienced in outreach, to work with Rhodes University students and postgraduates. The University of Bristol postgraduates assisted in a series of lecture demonstrations and practical workshops, mainly with resource-deprived schools in the Eastern Cape.

A Pollutant's Tale: A lecture demonstration with worldwide appeal

'A Pollutant's Tale' (APT) was created in 2005 by Dudley Shallcross, Professor of Atmospheric Chemistry at the University of Bristol, and by Tim Harrison, the Bristol ChemLabS School Teacher Fellow,² as a vehicle to teach elements of atmospheric chemistry and climate change to students and to include several demonstrations to explain these issues in a clear, amusing and memorable format. The lecture demonstration has since developed into a suite of performances according to age and prior knowledge and has now been performed in 12 countries on five continents to audiences numbering between 20 and 1000 at each lecture demonstration. APT has also become a major outreach vehicle at Bristol ChemLabS and at Rhodes University and is being presented by honours degree students, postgraduates, postdoctoral researchers, science museum demonstrators and academics. An estimated audience of 120 000 has seen APT performed to date.

The lecture demonstration does not require the specialist facilities of a modern lecture theatre, which makes it very useful when transporting it to schools that have no modern or large lecture facilities. Indeed, the 'Gases in the Air' version of APT that is normally given to UK primary school children does not require a data projector and can even be delivered outside of the school classroom in the open air. Most of the same demonstrations as those for APT are used for 'Gases in the Air', but the emphasis is on what is and is not a chemical

reaction, changes of state, and mixtures and compounds, rather than on climate change. Details of the experiments used within APT are given in the Appendix.

When working with audiences that include several younger teachers or less experienced teachers, the presenters also take care to explain, for the teachers' benefit, how to perform the chemistry demonstrations in the hope that some experiments may eventually be taken back into the classroom.

Hands-on primary school chemistry practicals

The University of Bristol uses a portfolio of practical work created for 10-year-old and 11-year-old learners to develop measuring, investigatory and teamwork skills. The usual format in the UK is three such experiments (referred to as a 'circus' of experiments) set up as individual stations, each led by a postgraduate student amongst which three groups of learners rotate.^{10,11,12,13,14} At Rhodes University the same experiments are utilised for grade 7 learners (aged 12–14), but the 'circus' is limited to only two experiments, because of time, space and economic constraints. These two experiments are both investigative in nature. In the first experiment, learners are required to use stopwatches to measure the time taken for a piece of magnesium ribbon to dissolve in various concentrations of hydrochloric acid. Once these measurements have been recorded, the learners are required to find the concentration of an unknown solution of hydrochloric acid based on the time it takes to dissolve the magnesium ribbon. In the second experiment, the learners investigate how the 'stickiness' of slime is affected by the amount of borax added to a fixed amount of polyvinyl alcohol. Before the learners start the experiments, they are given laboratory coats and safety glasses to wear, an experience in itself that excites these learners who seldom, if ever, find themselves in a laboratory environment. Sponsorship for the purchase of the laboratory and safety equipment is provided by Sasol.

Advantages of maintaining this level of chemistry outreach

Several advantages to the upscaling of outreach capacity were initially unforeseen by both chemistry departments. These are:

- In the UK, research grant providers introduced 'Impact Statements' in 2008 that require, as part of a grant application, a requirement to disseminate the results of research to a wider audience, including the general public.
- In South Africa, the publication of the 'White Paper on Higher Education' in 1997,¹⁵ made it clear that, in addition to teaching, or learning, and research, tertiary institutions are required to have community engagement as a third core activity.
- Aspects of chemistry outreach have been the subject of research by experienced teachers and other researchers as part of their Masters' degrees at the University of Bristol.^{6,16,17,18}



- Articles on climate have been published in journals aimed at school learners and teachers highlighting aspects of atmospheric chemistry, climate change and practical demonstrations used in chemistry outreach programmes.^{4,5,14,19,20,21,22,23,24,25,26}
- The young chemists involved in delivering chemistry outreach work are developing the 'soft skills' much in demand by employers. These skills include improved communication to audiences with differing backgrounds, presentation skills, time management and teamwork. In addition, these young chemists are highly valued role models to the learners with whom they engage.
- The University of Bristol and Rhodes University chemistry outreach collaboration has led to collaboration in aspects of atmospheric chemistry research – an example of chemistry outreach paving the way for research collaboration rather than the more traditional route of chemistry outreach as an example of research dissemination.
- Chemistry outreach not only promotes the profile of the individual chemistry departments, but also enhances the reputation of the respective universities in their surrounding communities. Other chemistry departments in each country also ultimately benefit from the promotion of chemistry to diverse multicultural communities in terms of potential student recruitment.
- Learners see chemistry as fun and applicable to their everyday lives and are more committed to pursuing Science as a subject of choice at high school.
- Chemistry outreach exposes students to new cultures. One University of Bristol postgraduate chemist who worked in South Africa stated 'I just wanted to thank you both for the fantastic opportunity of outreach in South Africa. The whole experience was completely mind-blowing and it'll be one that I'll never forget'. It can lead others into taking new career paths, including those in teaching and lecturing.
- Outreach partnerships have opened up new funding routes and have allowed for easier cascading of projects. An example of the latter is a UK Higher Education Academy project involving software support for biological and physics laboratory skills which needed international input.²⁷

Challenges in maintaining this level of chemistry outreach

To maintain good-quality chemistry outreach and to continue engaging with significant numbers of learners, consideration must be given to a number of factors, including:

- Large numbers of postgraduate students are required to be trained in chemistry outreach to alleviate the demand on a few which could negatively impact on graduate research studies. Having large numbers of demonstrators involved also prevents the possibility of burn-out that could occur if only a small cadre of students were engaged.
- Consumables and equipment need to be purchased, maintained and stored appropriately, which requires the involvement of technical support staff.

- Administrative support is needed to aid organisation within the department and between the department and the schools.

Transportation is needed to take material and people out to schools. Depending on local health and safety regulations, this need may mean that specialised vans have to be purchased, as was the case for the University of Bristol. In the Eastern Cape, distances are large, and with relatively porous balloons filled with gases, lecture demonstrations are therefore limited to schools within 2 hours of Rhodes University. Many of the schools do not have data projectors to show the MS PowerPoint presentation, whilst others have intermittent or no electricity. The absence of a school hall often necessitates the use of a classroom which can only accommodate a limited number of learners.

Sustainable growth without over-stretching both financial and human resources is required. At Bristol ChemLabS, the funds for engaging with about 30 000 learners per year come from a variety of sources. These sources include a fee paid by the schools for the chemistry outreach activities, support from alumni, funds raised through the commercialisation of software, some European Union grants and research grant 'impact' deliveries.²⁸ In the Eastern Cape, most schools engaged are too poor to be charged for engagement activities. Grants have been applied for, but because it is a core business of the university, the Department of Chemistry of Rhodes University does fund a limited amount of chemistry outreach. Funding for the initial trip to Bristol was procured from Afrox, and the initial purchase of equipment was funded by Sasol. In 2010, through Scifest Africa, Systemic Education and Extra-Mural Development and Support provided funding for a 1-week trip to present APT to nine Western Cape schools. Unlike the situation at the University of Bristol, all the chemistry outreach work at Rhodes University is done by full-time academic staff and postgraduate students who volunteer their time for this activity, which obviously limits the amount of work that can be done.

The future of these chemistry outreach projects

A joint project between Rhodes University and the University of Bristol, to take both the lecture demonstration and the primary workshops 'on the road' to more remote areas of South Africa, Namibia and Botswana in 2011 and 2012, is planned. This project has several aims. The first is to give an opportunity for a larger number of resource-deprived secondary school learners in these countries to see the lecture demonstration and to obtain hands-on practical chemistry experience. A second aim is to train volunteer undergraduate and postgraduate students from local universities in Namibia and Botswana to be able to deliver both the lectures and workshops for themselves and to undertake teacher training for groups of local science teachers in order to develop public understanding of climate change. Through this project, we aim to increase capacity to deliver chemistry outreach, as well as to enthuse teachers who have little experience of



delivering practical work and thereby spread this enthusiasm to do practical work amongst learners, with the hope that more learners will take Science as a subject until their school leaving examination ('matric') level. The additional value of having the participation of local university chemistry students is that the lectures and workshops can be delivered in a local language or the mother tongue of the learners rather than only in English.

The concerted chemistry outreach event in Namibia in 2011 will be delivered jointly by experienced chemistry outreachers from both Bristol and Rhodes universities, as well as by demonstrators from the Sci-Bono Discovery Centre in Johannesburg, who have been trained by University of Bristol staff on a previous occasion. A film crew from Rhodes University Department of Journalism and Media Studies are expected to make a documentary about the engagement.

Impacts of chemistry outreach projects

Several papers have looked at the impact of the University of Bristol's chemistry outreach on the school learners and teachers.^{2,6,10,12,14,16} Since this work started at Rhodes University, APT has been presented to over 2000 learners, ranging from grades 1–12, as well as to students and staff at Rhodes University. Most of the learners have been from resource-deprived schools, many of whom have never seen chemistry experiments being demonstrated.

When a teacher introduced the APT to his learners in a rural village near Peddie in the Eastern Cape, he said:

'We always think that the university is too far, it is not for us. But today the university has come to us, and now you can see that you can also go to the university.'

This summarises the impact – not only is chemistry made more accessible, but, through chemistry and interaction with postgraduate students, tertiary education seems more accessible. Barriers are broken down.

Lessons learnt from chemistry outreach

The introduction to APT and hands-on experiments by Bristol ChemLabS made it easy for the Department of Chemistry at Rhodes University to extend its community engagement activities. Although the APT presentation needed to be modified slightly to make it more relevant to the South African context, this process was less onerous than devising a new APT-like presentation. APT has universal appeal and thus it can be used to cross multicultural boundaries.

Postgraduate students at Rhodes University come from all over the world, and most of them have participated in taking APT to schools. This volunteer work is seen by both the students and the department as part of their postgraduate development. Many of them did not realise the state of education at schools in rural and peri-urban areas of the

Eastern Cape, and it thus creates an awareness of their privileged circumstances. The whole exercise of chemistry outreach also introduces the learners to people from different countries and backgrounds (and accents), thus providing an important opportunity for learners to identify with role models in science.

Chemistry is a practical subject and lends itself to hands-on work. The hands-on, real science investigative approach adopted in this collaboration, where the emphasis is on doing and discovering, is supported by a number of studies.^{28,29,30,31} Indeed, Roberts and Wassersug³² have conducted a retrospective study of a programme that ran from 1958 to 1972 which provided hands-on science opportunities. Their analysis showed that students were statistically more likely to pursue science as a career if they engaged in hands-on science whilst at school compared to those students who did not take engage in hands-on science until they entered university. Laursen et al.³³ have also outlined the many benefits to the providers, especially postgraduate students, that taking part in such activities provides, which is also a very important factor in this work. School learners need to think more to learn better; whilst 'talking science' has become a popular notion, there is also a requirement to support this development alongside 'real' scientists.

Summary

Establishing a sustainable outreach programme, developing appropriate activities, training initial and future teams, setting up collaborations with schools and then sustaining the programme, are difficult. However, once established, the positive impacts on both recipients and providers are sizeable. The collaboration between the University of Bristol and Rhodes University has been most beneficial; exchange of expertise and resources has accelerated programmes at both universities. The very great advantage of looking at issues from a number of cultural perspectives has been enlightening. Evidence shows that such long-term programmes do have a significant impact and there is already evidence that both programmes are achieving significant impacts.

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Competing interests

We declare that we have no financial or personal relationships which may have inappropriately influenced us in writing this article.



Authors' contributions

T.G. Harrison, D.E. Shallcross and N.C. Norman, based at the University of Bristol, developed and manage the programme of APT and the circus of experiments which are taken to schools. J.D. Sewry and M.T. Davies-Coleman are based at Rhodes University and have modified and continue with the outreach project in the Eastern Cape Province of South Africa.

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Appendix

Details of the practical demonstrations used in 'A Pollutant's Tale'

These demonstrations are the same in all versions of the lecture. Delivering new knowledge to the learner on atmospheric chemistry and climate change is only one aspect of their use. A suitably informed lecturer can also use the demonstrations to revise prior learning in chemistry.

The initial practical demonstration involves the ignition of 4 L – 5 L of hydrogen and helium gases, in separate helium-grade balloons tethered by a light string to a chair, using a lit taper attached to a 1-m ruler. Comments on gases in the gas giant planets can accompany this demonstration.

In a second demonstration, liquid nitrogen is poured into a clear glass Dewar flask to show it boiling. Rubber tubing (~1 m in length) is then inserted to demonstrate 'nitrogen rain' and to give the lecturer a 'liquid nitrogen shower'. The influence of the change in temperature on the flexibility of the cold rubber is demonstrated using a safety screen and a hammer. The change in the physical properties of rubber gloves, flowers, bananas and eggs (the 'fried egg' experiment) after immersion in liquid nitrogen quickly follows to emphasise the difference between chemical and physical properties.

The 'elephant's toothpaste experiment', using 35% hydrogen peroxide (200 mL), food colouring, washing-up liquid and potassium iodide (as the catalyst for the decomposition), is used to show oxygen formation.

Volatile organic compounds from biotic and anthropogenic sources are demonstrated using perfume components into which absorbent pieces of thin card are placed to allow learners to smell the common volatile organic compounds such as vanilla and spearmint oil.

Incomplete and complete combustion of fuels is then demonstrated. Water, washing-up liquid and calcium carbide produce acetylene foam; the foam is then ignited to demonstrate incomplete combustion. To demonstrate complete combustion, use is made of the 'whoosh bottle'



experiment where methanol or isopropanol vapour is burnt spectacularly. The 'whoosh bottle' experiment is available at: <http://practicalchemistry.org/experiments/enhancement/spectacular-demonstrations/the-whoosh-bottle-demonstration,240,EX.html>

Depending on the venue, nitrogen dioxide gas is then made against a white background so that the learners can easily see the brown gas. The gas is made using copper (~2 g) and concentrated nitric acid (~5 mL).

The sublimation of dry ice is demonstrated by placing some dry ice into a disposable latex glove and knotting the glove.

Dry ice is then put into a large beaker of water to which universal indicator and dilute sodium hydroxide have been added. The changes in pH are discussed, as is the physics of the cloud formation.

The demonstration finishes with the combustion of two more balloons filled with low density, unknown gases – both of which are hydrogen. It is important to finish with a bang.

A version of the MS PowerPoint presentation that accompanies this lecture demonstration may be found at: http://www.chemlabs.bristol.ac.uk/outreach/resources/PT2008_SciFest.ppt